§29. Computer Simulation on Fine Particle Behavior in Plasmas

Hirose, K., Kamimura, T.

Fine particles in plasmas are of current interest in plasma science and applications. The dynamic properties of fine particles in the presence of external electric fields is studied using Langevin molecular dynamics simulations. The dust particles attain a high negative charge q_d of order of $10^4 \sim 10^5 e$(electronic charge) and the diameter of the dust particles is a few micro meters in size. Crystallization of dust particles[1] comes about due to interaction of Coulomb's force acting on them[1]. A study of Coulomb crystals is useful not only to analysis for strong coupling plasma phenomena but also considering the transition process between liquid and solid states, relationship to solid-state physics.

Above all, in this study we will analyze a growth process of the Coulomb crystal of fine particles in electrostatic field as it was observed in experiments. In these systems, dust particles in an ion sheath mostly extend to the horizontal plane where they form a 2D crystal structure, with only a few particles in the vertical direction. However, three-dimensional structures extending in the z-direction in contrast to 2D have been observed by controlling the sharp profile of the horizontal potential and the wide profile of the potential in the z-direction[1]. As mentioned above, the growth process problem of fine particles is different in 2D and 3D solid states, therefore it was necessary to carry out particle simulations for both systems[2]. The important points of this study is to reproduce such as the Coulomb crystal formation, and considering whether our potential model is suitable.

The equation of dust particle motion in such a crystal can be written as

$$M\frac{d^2\mathbf{r}}{dt^2} = \mathbf{F}_e - \mu\frac{d\mathbf{r}}{dt} + \nabla U(\mathbf{r}), \tag{1}$$

where M is the mass of the dust particle, F_e is the electrostatic interaction force of the dust particles, μ is the friction coefficient of the particles with neutral gas, and U is the external potential. The structure of the dust crystal in its equilibrium state is defined by the confinement potential U. The Coulomb interaction force for acting on the each dust particles, is given by

$$F_e = \frac{q_{dust}^2}{4\pi\epsilon_0}\sum_{i,j}\frac{\mathbf{r_i} - \mathbf{r_j}}{|\mathbf{r_i} - \mathbf{r_j}|^3}. \tag{2}$$

Suiting the external potential to the experiment, we write it as follows,

$$U(r) = \alpha\mathbf{r}^2, \quad U(z) = \beta(z(i) - z(0))^2. \tag{3}$$

where, $\mathbf{r}$ is i-th particle distance of the radial direction, $z(0)$ is the equilibrium point of the gravity and the electrostatic force. Here, we set the parameters $\alpha = 6.0 \times 10^5 eV/cm^2$ and $\beta = 1.5 \times 10^5 eV/cm^2$, respectively. The other simulation parameters are taken from the experiment. The dust particle radius is $5.0\mu m$ and the mass ratio of the dust particle mass to the proton mass is $M_{dust}/M_{proton} \sim 3.75 \times 10^{14}$. The charge of the dust particle is $1.6 \times 10^{-15}c$, the distance between the dust particles is a few hundreds μm, and the temperature is $T_{dust} = 0.01 \sim 0.1 eV$.

We carried out a simulation suited to the above asymmetric condition($\alpha \neq \beta$). Fig.1 shows the simulation result in 3D. It was noticed that the strings have an asymmetric structure for the horizontal and z-component in three-dimension. Controlling potential in the radial and z directions, the three-dimen sional Coulomb crystal similar to the experimental vertical state is successfully reproduced by our simulations.

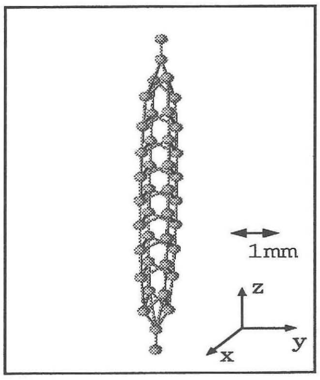

Fig.1: This figure is the simulation result for 40 particles. Here, we can observe that the fine particle formation of the Coulomb crystal is similar to the experiment result [1] in three dimensions .

References

1). N.Sato, *et.al.* FRONTIERS IN DUSTY PLASMAS(edited by Y.Nakmura et.al.) Elsevier Science B.V, 329(2000).

2). K. Hirose, *et.al.* *J. Plasma. Fus. Res.*(11th, Int. Toki. Conf, proc, p149)